APPLICATIONS OF CCD SENSORS IN PHOTOMETRY AND IN DAYLIGHT RESPONSIVE SYSTEMS

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Summary

This paper investigates a novel field of application of CCD sensors in photometry and in lighting control systems for utilization of daylight instead of the widely used silicon photodetectors.

Because of their technical specifications CCDs can be used as advanced light detectors. At present, portable devices, with CCD sensors as luminance meters, are used to evaluate the luminance, illuminance and glare levels in road lighting. Luminance distribution within the field of view is recorded using luminance mapping technology, based on CCD camera, in order to develop glare prediction models. High dynamic range (HDR) imaging offers the potential to use cameras as luminance meters. CCD cameras can be used to create luminance maps of scenes and to determine the intensity distributions and the near-field photometry of lamps and luminaires. Recently, goniophotometers with CCD sensors appeared in the market.

A promising application of CCD sensors is the determination of the daylight level inside a room. The sensor is placed anywhere on the ceiling and aims to the control zone. It captures images of the room with a wide field of view (the widest possible). The captured images are converted to real luminance images using image-processing routines. The corresponding light levels (illuminance) on the surfaces of the room are calculated by the luminance maps using light emitting models. The light levels on one or more parts of the room are calculated and compared to the desired levels (set-points). The installed luminaires are dimmed individually at the appropriate light level through a multi-signal output. As a result, the new system will be able to control the light levels properly and create comfort lighting conditions and visual comfort for all users of the room.

1. Introduction

A charged coupled device (CCD) transports electrically charged signals, and is used as a light sensor. A CCD chip is divided into pixels. Each pixel has a potential well that collects the electrons produced by the photoelectric effect. At the end of an exposure (frame), each pixel has collected an amount of electrons (i.e., charge) proportional to the amount of light that fell onto it. The CCD is then read out by cycling the voltages applied to the chip in a process called “clocking.” Due to the structure of a CCD clocking causes the charge in one pixel to be transferred to an adjacent pixel [1].

Devices that include light sensors (photosensors or image sensors) have many uses in scientific applications some of which are in photometry (light meters and goniophotometers), colorimetry and lighting control.

2. CCD sensor array operation

At the heart of a CCD camera is the CCD imager (Figure.1), a specialized type of integrated circuit (IC) which is located just behind the camera lens. The lens project a small image of the scene in front of it directly onto the CCD imager chip, which is behind an optical glass window. The CCD imager then scans the image, and with the help of a few support chips generates a signal. The operation of a CCD imager chip is quite complex, but we will try to simplify.

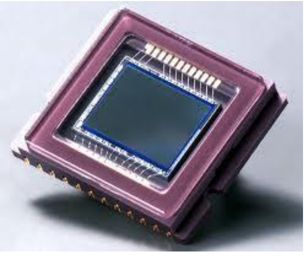

Figure.1: Charged Coupled Device (CCD) imager

Inside each cell there is a light sensitive element (photodiode) together with a charge-transfer area which forms part of a long vertical shift register. There are also two control elements, called the readout gate and the overflow gate, and a short section of a long vertical structure called the overflow drain. All parts of the cell apart from the sensor element are covered with metallization, so they are kept in the dark. When light falls on the sensor element (as part of the image), the photons generate charge carriers and as a result a small quantity of charge is accumulated in that part of the cell. The quantity of charge accumulated depends on the amount of light reaching the cell. The area directly under the sensor element is designed to contain this charge. Then, a voltage pulse is applied to the readout gate. Figure.2 shows the overall charge flow paths in the image sensor array.

So after the readout pulse, the charge that is generated in the sensor element by the incident light is shifted into the charge-transfer area alongside. And as mentioned earlier this area is actually part of a long vertical shift register, which links all of the charge-transfer areas in a complete column of cells. This shift register is used to transport the charges in each of the charge-transfer areas down the columns, and ultimately out of the chip.

The procedure to pass the charge in each charge-transfer area down to the one below it, is identical to the process used to shift the charges into them from the sensor elements. There is another set of gates between each pair of adjacent transfer areas in the column, and, by pulsing, the charges are transferred from each area to the one below.

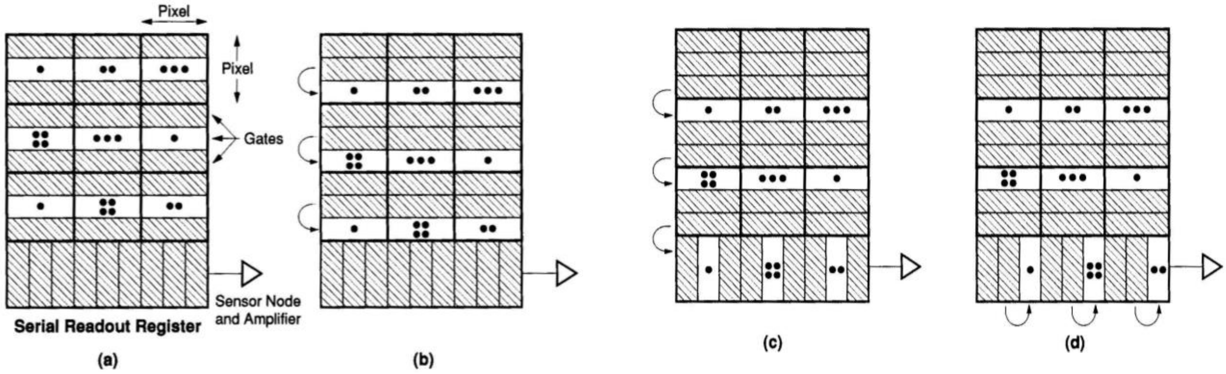

Figure.2: Representative CCD operation of a 3x3 array with three gates per pixel. Nearly all the photoelectrons generated within a pixel are stored in the well beneath the pixel. (a) The CCD is illuminated and an electron image is created. (b) The columns are shifted down in parallel, one gate at a time. (c) Once in the serial row register, the pixels are shifted right to the output node. (d) The entire serial register must be clocked out before the next packet can be transferred into the serial readout register [2].

Along the bottom of all the columns, there is another one of these shift registers, the only horizontal. So by giving pulse in the transfer gates linking the bottom row of charge-transfer elements, the charges in them can be shuffled out of the image array, in serial order. Here they pass through a charge-to-voltage amplifier stage to produce the output signal [1-2].

3. CCD imager applications in photometry and colorimetry

Recently, CCD cameras have been used in photometry instead of conventional photsensors. High dynamic range (HDR) imaging offers the potential to use cameras as luminance and illuminance meters. The luminance maps obtained by HDR photography can be analyzed according to objects, figures, visual tasks, colors and luminance. The corresponding illuminance contributed by each feature can be calculated. This allows a new way of illuminance analysis to measure the quantity of light due to specific objects, colors and features [3]. A new Goniophotometer has been constructed with CCD sensors in the place of photocells, to measure the brightness radiated from the active lighting surfaces of the lamps [4]. Other detection methods using CCD cameras to photograph the light source, calculate the distribution of the illumination light source quickly, quantificate glare and measure reflection properties of the surfaces [5-7].

The contribution of the CCD cameras to road lighting is great. Cameras mounted on moving vehicles make real-time measurements on the road surface. Using image processing techniques we can evaluate the road lighting without distribution of the road function [8]. In another study the vehicle mounted cameras are pre-calibrated to estimate the ratio between gray value of light images and lighting parameters (luminance and illuminance). Appropriate infra-red and neutral density filters are employed to control the wavelength and limit the light entering the cameras. Automated image analysis methods are further developed to speed up the position and image analysis process. Multidirectional measurements of light output are achieved by using multiple journeys and multiple cameras on the same road-segment and this provides data on different observation lines. Interpolation techniques are employed to estimate the complete profile and produce isolux contours [9, 10].

In the field of colorimetry, there are spectrometers that use a charge coupled device (CCD) to measure the energy of incident photons. CCD spectrometers can be sensitive to a wide range of wavelengths, from infrared and optical to ultraviolet and X-rays. Each incident photon generates electrons in the CCD, the number of which is proportional to the energy of the original photon. The steps of the color measurement are as follow: a specific software stores reference and dark measurements correct instrument response variables, the light is transmitted through an optical fiber to the sample, the light interacts with the sample and finally another optical fiber collects and transmits the result of the interaction to the spectrometer. The spectrometer measures the amount of light and transforms the data collected by the spectrometer into digital information. The spectrometer passes the sample information to the specific software, which compares the sample to the reference measurement and displays processed spectral information.

The artificial reproduction of some coloration effects (for instance nacre aspect, iridescence) which appear spontaneously in materials used in interior architecture a right description of the different mechanisms, and, especially, a detailed analysis of the spectral behavior of the light scattered by such surfaces are involved in these phenomena. To this aim, a specific set-up has developed for the recording of the reflectance distribution function of solid samples in the whole visible spectral range. By implementing different methods is allowed the description of the color information for scattered light. In the specific study, experimental results obtained on some glass windows are given [11].

4. CCD imager applications in lighting control

A major problem with a conventional closed loop photosensor is the placement of the sensor. If the sensor is located in such a position that it has a direct view of the daylight delivery system, there is a possibility that the daylight distribution may change during the day, resulting in a change in the ratio of workplane illuminance and photosensor signal. This may cause the photosensor to dim down the luminaries to a not acceptable level. Also, if the photosensor has a view of the luminaires light area it is controlling, a problem of oscillation may arise as the dimming level of the luminaire rises and lowers in quick succession, resulting in unstable operation. Since the photosensor signal depends on the position of the sensor relative to the room configuration, both commissioning and calibration play a vital role in determining whether the system can achieve significant energy savings without raising serious problems to the users [12].

There have been efforts to embody new technologies by developing photosensors using CCD or CMOS image sensors instead of photodiodes [13-16]. These sensors are quite promising, in the sense that they can measure luminance patterns [17] same as the human visual system and that they can replace multiple sensor systems. A single sensor can monitor a set of task positions that require different illuminance values, and adjust the artificial lighting system in response to daylight. A direct view of the illuminated area of the luminaires or windows is allowed, as long as lens scattering is minimal. Such system can be designed to account for reflectance changes to the calibrated surfaces by sensing surface color and automatically shifting to neighboring pixels when needed. The system can be operated as an embedded system, with all processing carried out locally, or an Ethernet for remote processing to achieve greater flexibility. The system may also be used to sense occupancy through detection of movement within the image [14].

5. A proposed lighting control system with CCD cameras

Our aspect is the development of a new lighting control system based on a digital CCD imaging sensor and intelligent control algorithms, Figure.4. The proposed system aims to minimize the limitations of the conventional technology of photosensors and to develop a reliable system that uses new control algorithms based on image processing techniques. A description of the workflow of the proposed system can be summarized in the following basic steps:

- The new image sensor (CCD Camera) can be placed at any point of the ceiling and aims to the control zone. The CCD sensor captures images of the task area with a wide field of view (as wide as possible). The captured images are converted to real luminance images using image-processing routines (algorithm). The light level on one or more parts of the room is calculated and compared to the desired levels (set-points), Figure.3. Three experimental set-ups are designed to be used for the calibration procedure. The first one will be used for two reasons, a) Calculation and elimination of the CCD lens' peripheral brightness reduction effect (vignetting) and b) calculation of the dynamic range of the sensor. A second set-up will be used to obtain the colour response of the CCD using, among others, a monochromator and various standard light sources. Finally, the third set-up will be used in order to test the accuracy of CCD measurements and to calculate correction factors, using chromatic targets of common materials and various light sources.
- The corresponding light levels on one or more surfaces of the room will be calculated by the new operational equations and the illuminance values according to the desired light levels. The illuminance values will be calculated from the luminance maps.
- The new control algorithm will calculate the proper conversions of the CCD output regarding its position. An algorithm (DALI Algorithm) will also correct illuminance values taking into account daylight and artificial light spectra and a model that calculates the proper function of a photosensor with respect to the adequacy of light and users' behavior, Figure.3.
- The installed luminaires (that will use DALI EDBs) will be dimmed by individually at the appropriate light level through a multi-signal output. Digital Addressable Lighting Interface (DALI) is a standard protocol (open code) for communication between the individual components of a lighting system (dimmable ballasts and light sensors). The DALI Busmaster is the communication line between the luminaires that have DALI Electronic Dimmable Ballasts and the computer. Through the personal computer the busmaster gives the commands to the EDBs in order to be achieved the desirable light levels in the work place taking into account the daylighting levels.

As a result, the new system will be able to control the light levels properly and create comfort lighting conditions and visual comfort for all users of the room.

The proposed system (Figure.3) will exploit the up-to-date and innovative development in the field of CCD sensors. It is worth mentioning that there is not yet a commercial CCD sensor for the purpose of this study. Therefore, the sensor must be developed from an early stage. Namely, the full CCD photosensor must be built up from the beginning. After a thorough search of the market, a set of CCD sensors that meets the technical requirements of the project will be chosen. This kind of sensors is not incorporated in commercial cameras but is used in inquiring applications that develop new products. Practically the sensor will be acquired in a primitive stage along with the corresponding basic software. The extent of the development and tuning of a) the sensor and b) the application software depends on the user. In this case, the sensor will be assembled with suitable lens and V(λ) filters in order to correspond to the human visual system.

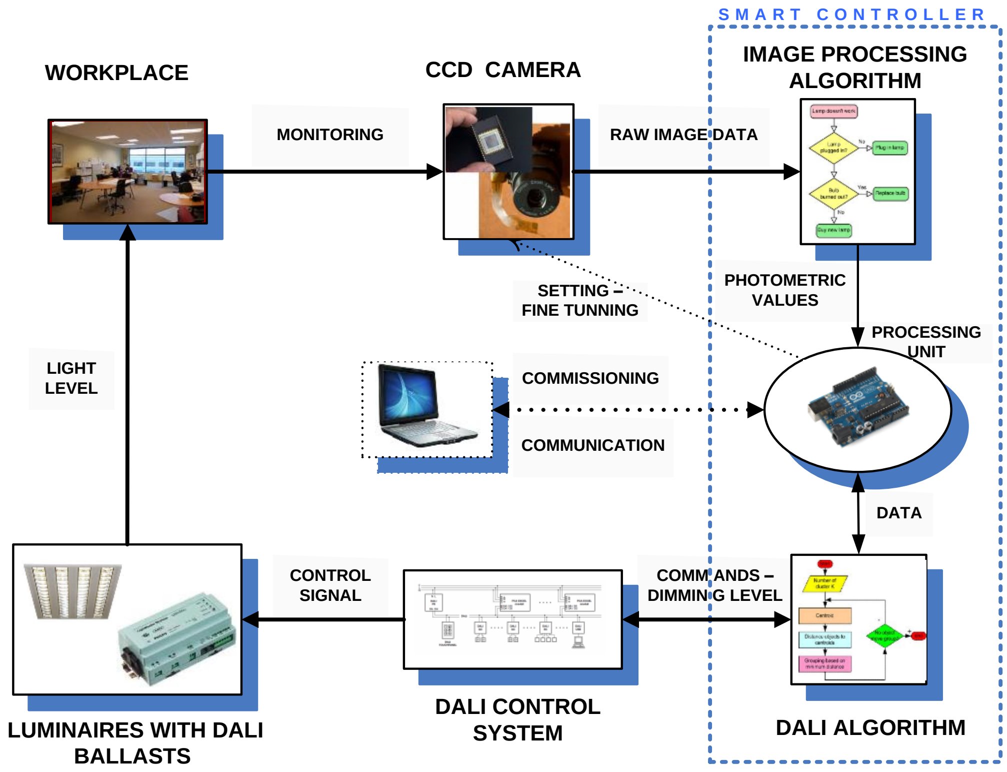

Figure.3: Block diagram of the system

Current standards define the desired lighting levels in a room, which are expressed in illuminance values (lux). The CCD sensor will be calibrated to measure luminance values (candela per square meter) with the highest possible accuracy in any conditions. As luminance values depend on the direction of view, a set of algorithms will be developed in order to calculate the lighting level of any area of the room using the captured image. Images will be examined, captured by both colour and monochrome CCD sensors. This will be based on the reflection characteristics of common materials, their colour characteristics as well as other image processing techniques.

The final product will be an outcome of procedures that involve research and measurements in the laboratory. Since any CCD photosensor does not exist in the market, the proposed one could be characterized as a prototype. This gives an added value to the research, because it could be applied to real installations of lighting controls as an innovative component.

The image processing, in order to calculate the intensity of light in every pixel of the captured picture, will require original inquiring effort. The final result will be really innovating, because it will embody CCD sensors with state-of-the-art image processing in lighting control systems for daylight harvesting. For the control of the sensor an advanced controller (built up from an early stage for the purposes of the project like the CCD) will be used and the appropriate software and algorithm will be developed. This kind of research has been found in very few cases in the international bibliography but without development either of the image processing or of the controller.

6. Conclusions

According to the international bibliography CCD imagers can offer excellent imaging performance when designed properly. They have provided the performance benchmarks in scientific applications, such us photometry and colorimetry, which demand high image quality.

Relative to the lighting control, the whole system will be using prototype components from the CCD sensor and the controller to the software (image processing and control algorithms). The combination of all the above-mentioned components creates an original and innovative final product (the final system) that can be used straightforward for the control of artificial lighting. The precise exploitation of daylight with the innovative system will result in a better energy saving, an optical comfort for the users and an unerring function of the dimming.

There is a lack of publications in international bibliography concerning similar research. This can be verified by the superabundance of installations of control systems with conventional photosensors worldwide without anyone among them being based on sensors with CCD camera. An extensive search in the catalogues of the relative manufacturers will confirm the non-existence of this technology of lighting control.

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